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EVALUATION OF INSTRUMENTATION FOR TESTING LARGE GENERATOR SETS.(U)
FEB 78 W D FORD, M J POLLOCK

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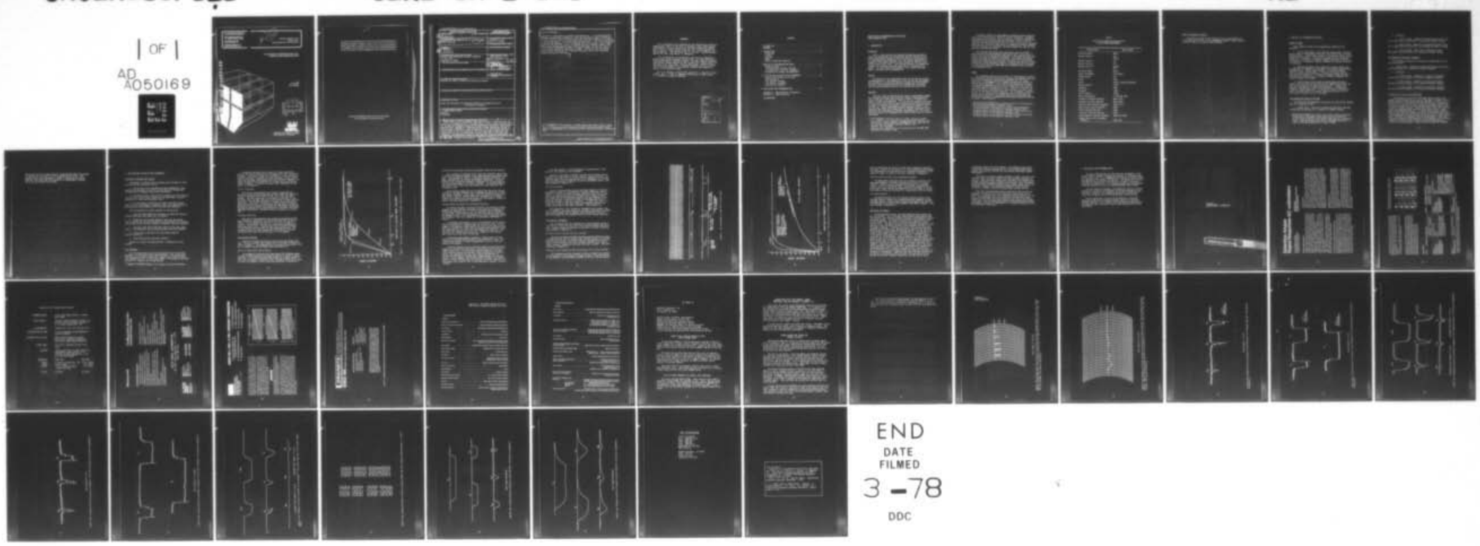

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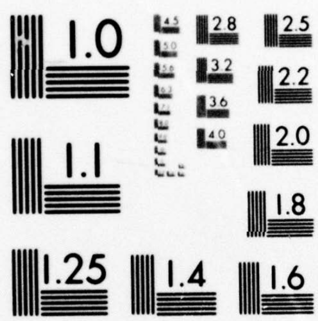

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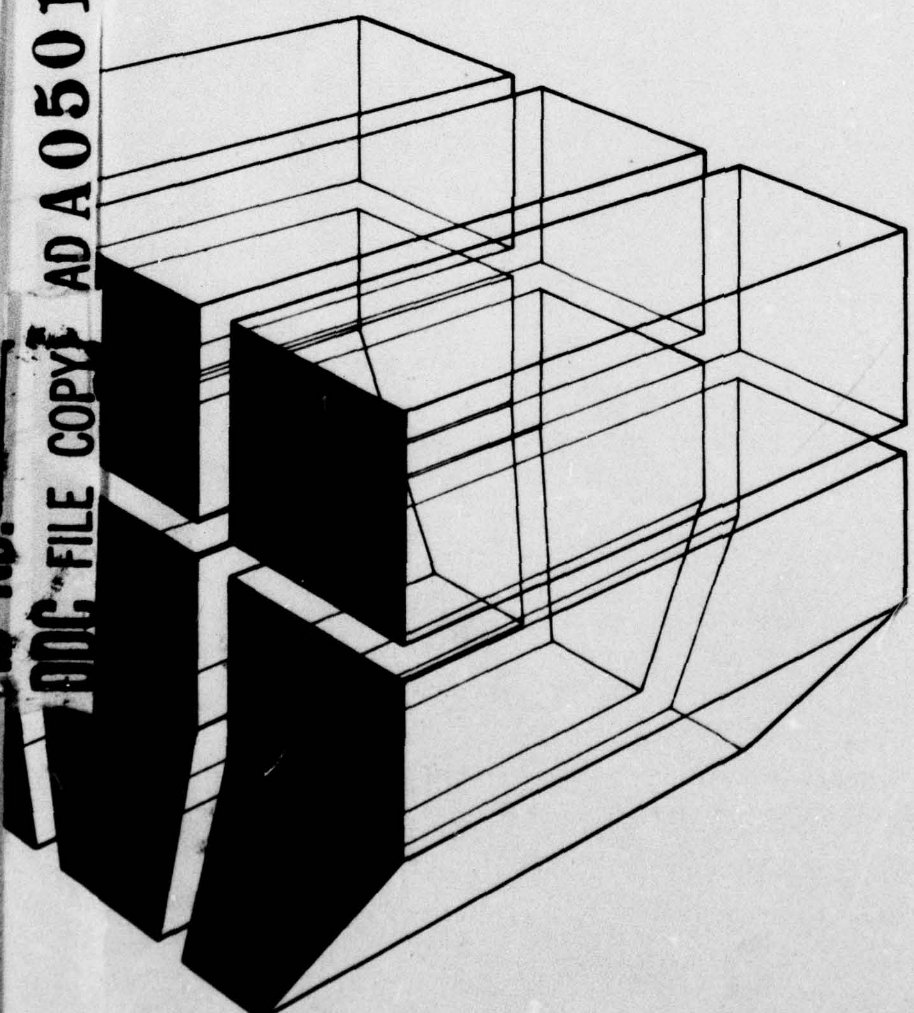
SPECIAL REPORT E-121
February 1978
Large Generator Set Test Procedures

EVALUATION OF INSTRUMENTATION FOR TESTING LARGE GENERATOR SETS

by
W. D. Ford
M. J. Pollock



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This report, which supplements CERL Special Report E-103,* presents the results of an investigation of instrumentation for use in measuring and recording voltage and frequency changes during performance testing of large engine-generator sets intended for stationary electric power generation service in fixed military facilities. Based on analysis of (1) the specific characteristics needed to fulfill the end use for which the electric power will be produced and (2) the instrumentation currently described in MIL-HDBK-705B, inadequate instrumentation, primarily that used for transient measurement, was

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selected for replacement by advanced instrumentation. Five advanced instrumentation systems were selected for field testing based on their suitability for field testing, their recording capability, and their capability to measure in the desired range. The system which performed best in the field testing was the Gould 2200 Recorder. It is recommended that this recorder system, supplemented by a Dranetz line monitor to prevent accuracy problems caused by the Gould system's dependence on paper slip and pen width, be used for testing utility-grade and medium-grade power systems. Testing of precision-grade systems would require use of a transient digitizer system with subsequent computer analysis of the data.

*E. M. Takemori, S. W. Lee and M. A. Gazda, *Stationary Diesel Engine - Generator Set Acceptance Testing Procedures, Methods, and Instructions*, Special Report E-103/ADA037545 (U.S. Army Construction Engineering Research Laboratory, 1977).

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FOREWORD

This investigation was conducted for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A763734DT08, "Military Construction and Field Engineering Development"; Task 07, "Power System"; Work Unit 001, "Large Generator Set Test Procedures." The applicable QCR is 3.02.006. The OCE Technical Monitor for this study was Mr. S. Berkowitz.

This investigation was performed by the Electrical-Mechanical Branch (EPM), Energy and Power Division (EP), U.S. Army Construction Engineering Research Laboratory (CERL). The CERL Principal Investigators were Mr. Edward Takemori and Mr. Dominic Eng. Appreciation is expressed to Mr. James Hall, Electronics Engineer, for his contribution in the development of the computer software and hardware required in the evaluation phase.

Mr. R. G. Donaghy is Chief of EP, and Mr. M. J. Pollock is Chief of EPM. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

EVALUATION OF INSTRUMENTATION FOR TESTING LARGE GENERATOR SETS

1 INTRODUCTION

Background

The U.S. Army Construction Engineering Research Laboratory (CERL) has established and standardized specific methods for obtaining measurements needed to test and evaluate the performance of large diesel engine-generator sets and related components intended for stationary electronic power generation service within fixed military facilities.[1] Such testing requires instrumentation systems for recording transient conditions of voltage and frequency. The investigation documented in this report was undertaken to evaluate such instrumentation.

Purpose

The purpose of this investigation was to evaluate and develop recommendations for instrumentation to be used for the measurement and recording of voltage and frequency changes during performance testing of large engine-generator sets intended for stationary electric power generation service in fixed military facilities.

Approach

The first step in determining the types of measurements needed to accurately represent the electrical output of engine-generator sets as defined in CERL Special Report E-103[2] was to define the grades of power being measured. This was done by examining the probable end use of the electric power produced and analyzing each type of power to determine the specific characteristics needed to fulfill the end use. These characteristics were compared with the instrumentation described in MIL-HDBK-705B[3] to identify inadequate instrumentation for replacement by advanced instrumentation. The instrumentation found to be inadequate was primarily that used for transient measurement.

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[1] E. M. Takemori, S. W. Lee, and M. A. Gazda, *Stationary Diesel Engine-Generator Set Acceptance Testing Procedures, Methods, and Instructions*, Special Report E-103/ADA037545 (U.S. Army Construction Engineering Research Laboratory [CERL], 1977).

[2] Takemori, Lee, and Gazda.

[3] *Generator Sets, Measurements and Instrumentation*, MIL-HDBK-705B (Department of Defense, 1972).

Equipment suitable for measurement of transient power characteristics was identified by a review of current literature. Equipment manufacturers were queried, and the currently available equipment was selected based on the published specifications. Since it was not practical to obtain specifications for all available types of equipment. selection was limited to those which (1) appeared to be most suitable for field testing, (2) provided a recording capability, and (3) could measure in the desired range.

The selected instruments were then tested using a suitably amplified and calibrated computer-generated signal, which could reproduce any desired voltage and frequency for any specified time (see Table 1 for other instruments considered). The tested instruments' capability to measure and record the test signal with the required degree of accuracy was then evaluated. Based on the results of these evaluations, instrumentation systems are recommended for replacement of those specified in MIL-HDBK-705B for transient testing of diesel engine-generator sets.

Scope

This document presents an evaluation of instrumentation systems for recording transient conditions of voltage and frequency which may occur in the testing of large engine-generator sets for fixed facilities. Instrumentation for standard steady-state testing, as defined in MIL-STD-705B,[4] is not specifically addressed, although the systems recommended herein are also suitable for that function. A limited number of systems were tested. Selection of systems for testing was based on manufacturers' specifications and their suitability for the type of testing required. The instruments evaluated are for use in recording test information and to replace oscillographic and oscilloscopic instruments specified in MIL-HDBK-705B, the Corps of Engineer's Construction Guide Specifications CE 303.20,[5] CE 303.21,[6] and CE 303.22.[7]

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[4] *Generator Sets, Engine-driven, Methods of Tests and Instructions*, MIL-STD-705B (Department of Defense, 1972).

[5] *Generating Units, Diesel-Electric, 10-99 kW, With Auxiliaries*, CE 303.20 (Office of the Chief of Engineers [Draft], 1977).

[6] *Generating Units, Diesel-Electric, 100-300 kW, With Auxiliaries*, CE 303.21 (Office of the Chief of Engineers, 1961).

[7] *Generating Units, Diesel-Electric, 300-1500 kW, With Auxiliaries*, CE 303.22 (Office of the Chief of Engineers, 1961).

Table 1

List of Instruments Considered for Precise Power Measurements

Manufacturer	Model Number
Esterline Angus	A601C
General Electric	CH3 636x18
General Electric	CH4
General Electric	CF-1
General Electric	836x89 CH3
Esterline Angus	A601C
Texas Instruments	Recti/Peter
Sargent Welch	XKR
Brush	2400
Brush	Special Purpose Recorders
Hewlet Packard	7414A
Honeywell	1888
Honeywell	1508C
Hewlet Packard	7402A
Heath Schlumberger	Sr 206 Dual Pen
Biomation Transient Recorder	Model 1015
Hathaway Transient Recorder	Model ATM-1
Physical Data Transient Recorder	Model 512 A
Quanta Log Transient Recorder	Model
Erdac Transient Recorder	Model
Tektronix Transient Recorder	Model
Inter-Computer Transient Recorder	Model PTR 9400
Dranetz Power Line Disturbance Analyzer	Model 606

Mode of Technology Transfer

Technology transfer of the results of this investigation will be through specification of the recommended systems in Guide Specifications CE 303.20, CE 303.21, and CE 303.22.

2 ANALYSIS OF INSTRUMENTATION NEEDS

Grades of Power

Three grades of power to be produced were identified and defined*:

1. Utility-grade power, which supplies normal loads, including heaters, motors, and mechanical controls, was assigned the following characteristics: steady state voltage ± 2 percent of nominal (120V); steady state frequency, ± 2 percent of nominal (60 Hz); transient excursions, ± 10 percent of nominal voltage with return to normal in 5 seconds and ± 5 percent of nominal frequency with return to normal in 5 seconds.

2. Medium-grade power, which supplies electronic loads such as computers and communication equipment, was assigned the following characteristics: steady state voltage, ± 1 percent of nominal (120 V); steady state frequency, ± 1 percent of nominal (60 Hz); and transient excursions, ± 5 percent of nominal voltage and return to normal in 2 seconds, and ± 2 percent of nominal frequency and return to normal in 2 seconds.

3. Precise power, which supplies sophisticated electronic systems such as precision radar and missile command and control systems, was assigned the following characteristics: steady state voltage ± 0.25 percent; steady state frequency, ± 0.25 percent; transient voltage excursions, ± 2 percent of nominal voltage with return to normal within 1.0 second; frequency excursions, 0.5 Hz with return to normal within 1.5 seconds.

Instrumentation Accuracy--Voltage

The following instrumentation accuracies are required for measurement of voltage deviations:

1. Steady state. Capability of measuring deviation from test voltage with an accuracy of ± .5 percent of nominal voltage.

* The grades of power are related to the total systems performance. Current Corps of Engineers Guide Specifications CE 303.20, CE 303.21, and CE 303.22 do not specify power quality or grades of power. These definitions were used in instrument evaluation in order to provide guidance for all types of power.

2. Transient

a. Utility grade. Capability of measuring deviation from test voltage with an accuracy of ± 2 percent of nominal voltage.

b. Medium grade. Capability of measuring deviation from test voltage with an accuracy of ± 0.75 percent of nominal voltage.

c. Precise grade. Capability of measuring voltage deviations with an accuracy of 0.1 percent of nominal voltage.

Instrumentation Accuracy--Frequency

The following accuracies are required for measurement of frequency deviations:

1. Steady state. Capability of measuring frequency deviation with an accuracy of 0.2 percent of nominal frequency.

2. Transient

a. Utility grade. Capability of measuring frequency deviation with an accuracy of 2 percent of nominal frequency.

b. Medium grade. Capability of measuring frequency deviation with an accuracy of 1.0 percent of nominal frequency.

c. Precise grade. Capability of measuring frequency deviation with an accuracy of 0.1 percent of nominal frequency.

Evaluation of Current Instrumentation

Instrumentation specified in MIL-HDBK-705B was found to be generally satisfactory for use with utility power. However, oscillographic methods of measuring transients (Methods 101.1 and 104.1), while useful, are not practical for medium- and precise-grade power. Use of an oscilloscope for fast transient measurement requires use of special trigger circuits. Where step values rather than absolute values are being measured, the oscillatory nature of the signals makes interpretation difficult. To avoid these problems, measurement of the difference between the average of root-mean-square (rms) voltage measured as direct-current (dc) voltage gives a much clearer result. Deviation of frequency from a 60-cycle normal is even more difficult to analyze when presented in oscillographic form, since the speed of the paper or the clarity of the picture degrades the accuracy of the measurement. Measuring both voltage and frequency

deviations with this method requires interpretations which are subject to question by the supplier of the equipment being tested. CERL Special Report E-103 recommends a change in measuring the voltage waveform. MIL-HDBK-705B instrumentation as recommended in Methods 101.1 and 101.4 should not be used.

3 SELECTION AND TESTING OF NEW INSTRUMENTS

Selection of Systems for Testing

Instruments to replace the oscillograph were selected for testing based on the following criteria:

1. The ability of the instrument and the accompanying signal-conditioning equipment to provide a clear measure of voltage and the deviation of frequency from normal (60 cycles).

2. The manufacturers' specifications showing that the characteristics of each type of power, especially the transients, could be presented in a clear and uncluttered form.

3. The instrument's capability to record transient measurements in solid state memory, on magnetic tape, or on paper charts to allow analysis and evaluation after the tests were completed.

The instrumentation systems selected for testing were:

1. Esterline Angus Model 601C Voltmeter and Model AW Frequency Deviation Recorder (one channel per instrument)

2. Midwestern Oscillograph Recorder (used with the Active Control Voltage rms voltage transducer and the Rochester Instrumentation Systems Series FCX-1-60 frequency transducer) (multiple channel)*

3. Honeywell Fiber Optics Recorder (used with the same transducers as the Midwestern Oscillograph Recorder) (multiple channel)*

4. Dranetz Series 606 Power Line Disturbance Analyzer (multiple channel)*

5. Gould 2200 Recorder (multiple channel).*

Appendix A presents the manufacturers' information on these systems.

Test Procedure

Each instrumentation system was evaluated within the limiting parameters of the manufacturer's specifications. The systems were evaluated based on their capability to measure the actual transient with adequate accuracy for each power grade. The parameters used were deviation in frequency and voltage applied.

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* Capable of showing frequency and voltage on the same recording.

A computer-developed signal source of closely controlled accuracy was used to evaluate the instruments for both voltage and frequency. The digital signal was converted to a sine wave with a suitable interface (a digital to analog converter), and a trigger signal was provided simultaneously with the transient imposed. The signal was amplified and adjusted for voltage using a calibrated digital voltmeter. Frequency variations were programmed into the signal in the computer.

Voltage Conditions

Each set of instrumentation was tested to determine the measured voltage deviation when the applied voltage was changed by a step of 5 percent for periods of 1/8, 1/10, 1/32, and 1/64 seconds. The step change was in the negative direction for the specified time, and then returned to the original voltage (positive direction). The voltage returned to a steady state condition between each period test. The deviation from the actual voltage as measured by the instrument being tested was determined and plotted. The applied voltage was set and measured by a currently calibrated DANA Model 4300 digital voltmeter having an accuracy of 1.03 percent.

Frequency Conditions

Each set of instrumentation was tested to determine the measured frequency change when the applied frequency was varied by a step of 1 Hz for periods of 1/16, 1/8, 1/4, 1/2, 1.0, and 2.0 seconds. The frequency returned to a steady state condition between each period test. The deviation from the actual frequency as indicated by the instrument was determined and plotted. The frequency signal from the computer was controlled by a crystal-controlled oscillator with an accuracy of ± 0.01 percent.

Test Results--Voltage

Appendix B presents the data recorded during the voltage test runs. An error analysis and a comparison of instrument response are given in Figure 1. The repeatability of the test was 100 percent with all instruments except the Dranetz 606 (see Appendix B).

Esterline Angus Model 601C Voltmeter

The response of the Esterline Angus Model 601C Voltmeter began to drop for time intervals less than 1/8 second, as shown in Figure 1. Therefore, if accurate amplitude measurements of voltage changes of less than 1/8 second are required, this instrument should not be used. For test run examples, refer to the data recordings in Appendix B.

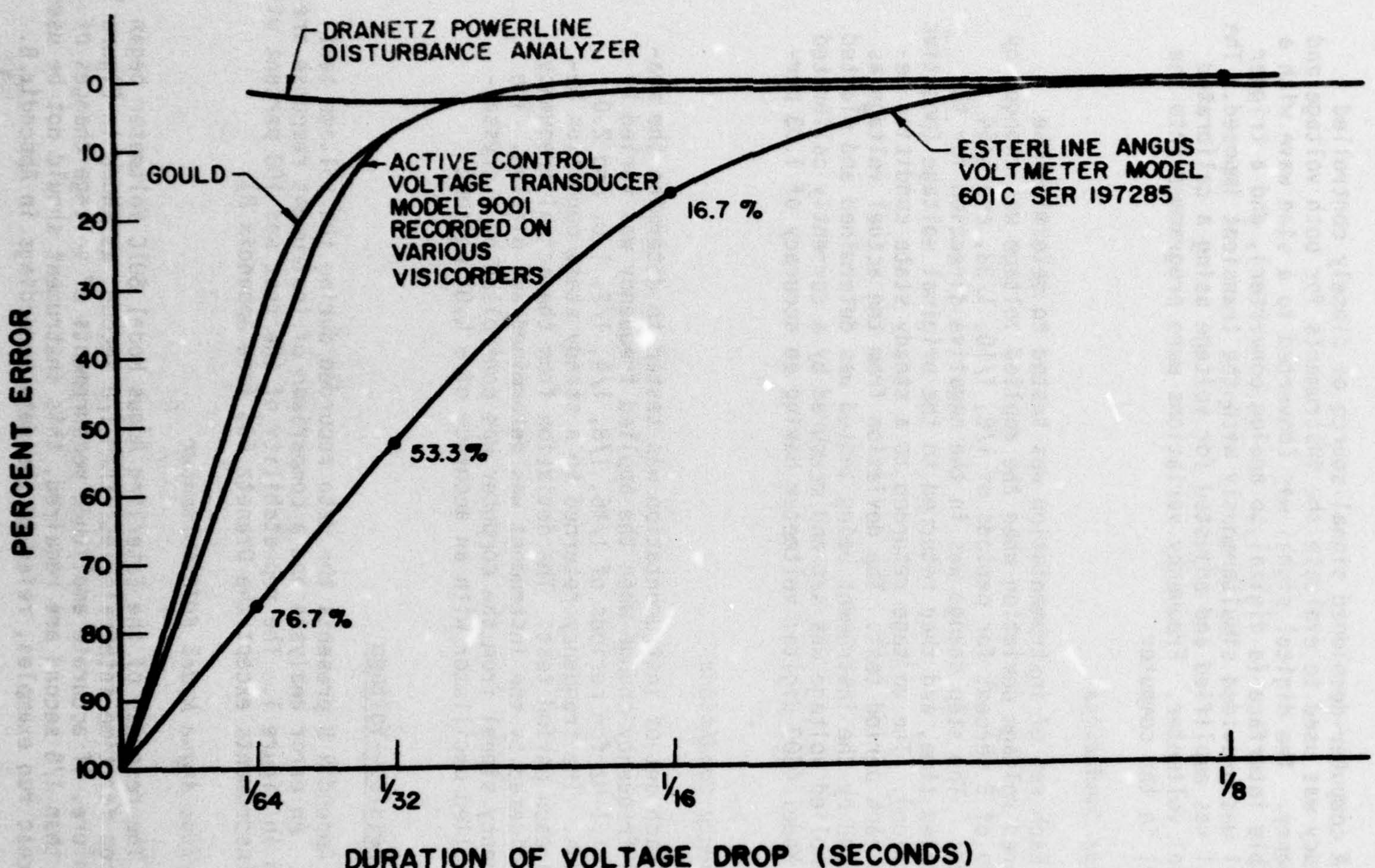

Figure 1. Error analysis and comparison of instrument response for voltage change.

Midwestern Oscillograph Recorder and Honeywell Fiber Optics Recorder

With a properly attenuated input, these two recorders can be used to record the waveform produced by the power-generating equipment under test. This approach is useful in detecting waveform distortion, but makes frequency and rms voltage measurements cumbersome. Using appropriate rms voltage and frequency transducers is the best means of making such measurements with these recorders. The transient-measuring capabilities of the resulting systems are then limited by the transducers used.

Since previous experience has indicated that the Active Control Voltage rms voltage transducer has a response equivalent to or better than others available, it was used as the rms voltage transducer for these tests. Results indicate that this transducer has a response limited to transient rms voltage changes of 1/16 second or longer, as shown in the data recordings in Appendix B.

Dranetz Series 606 Power Line Disturbance Analyzer

The Dranetz recorder continuously monitors the measured voltage; however, it only provides a printout of the variation exceeding the established threshold (a 2, 5, or 10 V threshold can be selected). In such cases, the recorder prints out the value and the duration of the change in cycles. All disturbances are classified by the Dranetz micro-computer into three categories--slow/average, SAG/SURGE, or impulse.

In SAG/SURGE measurements, up to 15 disturbances can be stored; they are printed out in sequence when the printer is free. If the number of disturbances stored reaches 16, the internal computer automatically switches to a short-term accumulated count mode and stores the summarized data for print out after conditions stabilize. The analyzer also automatically prints out a summary of the previous day's activity at the start of each day.

Slow/average measurements represent a steady state rms level based on a 10-second moving average of the monitored voltage. The slow/average printout is always accompanied by the time in hours, minutes, and seconds.

Transient impulses having a duration between 0.5 and 100 microseconds are continuously monitored in two-cycle periods holding the highest peak value. If one or more impulses measured in any two-cycle intervals exceed the threshold value selected by the impulse switch, the analyzer prints the time, channel designation (if monitoring three phase), highest peak value measured, and the word *impulse*. As an example, the printouts C0144 V Impulse, and C0195 V Impulse 17:59:01 indicate that two impulses--one with a peak of 195 V and another with a peak of 144 V--were measured on channel C input at 17:59:01.

The time duration of 100 microseconds to approximately 1/128 second is not covered by the instrument.

Testing of the Dranetz recorder revealed that although the performance is as specified, it is best used as a monitor of short- and long-term power line disturbances and is not recommended for specification testing because it does not provide a continuous record. (See data recording in Appendix B.)

Gould 2200 Recorder

Figure 1 indicates that the rms amplitude response of the Gould recorder in respect to the duration of voltage change was slightly better than that of the other systems tested when used with its own plug-in alternating-current (ac) voltage to rms voltage converter. This should not be interpreted as meaning that the response of the Gould pen recorder is superior to that of the Midwestern Oscillograph and Honeywell Fiber Optic Recorders. It means only that it is as good as or better than the system's performance (recorder plus signal conditioner) using those recorders. (See Appendix B.)

For comparison, an ac voltage was recorded on one channel, and an rms voltage of the same signal was recorded on the opposite channel. The contrast between the two methods can be observed in Figure 2, which also shows the time response lag of the rms voltage recording.

Test Results--Frequency

The instrumentation was subjected to a step frequency change of 1 Hz for 2, 1, 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 second time intervals. Figure 3 shows the response to the tests; the data recordings are presented in Appendix B.

Esterline Angus Frequency Deviation Recorder

The Esterline Angus Frequency Deviation Recorder Model AW showed a 30 percent error for the longest time interval tested; its response worsened progressively as the time interval shortened (see Figure 3). Figure 3 also indicates that this instrument should not be used to detect frequency changes of durations less than 4 seconds. (See data recording in Appendix B.)

Midwestern Oscillograph Recorder and Honeywell Fiber Optic Recorder

The frequency deviation response of these recorders was limited by the response of the frequency transducer used. The specifications of the Rochester Instrumentation Systems series FCX-1-60 transducers

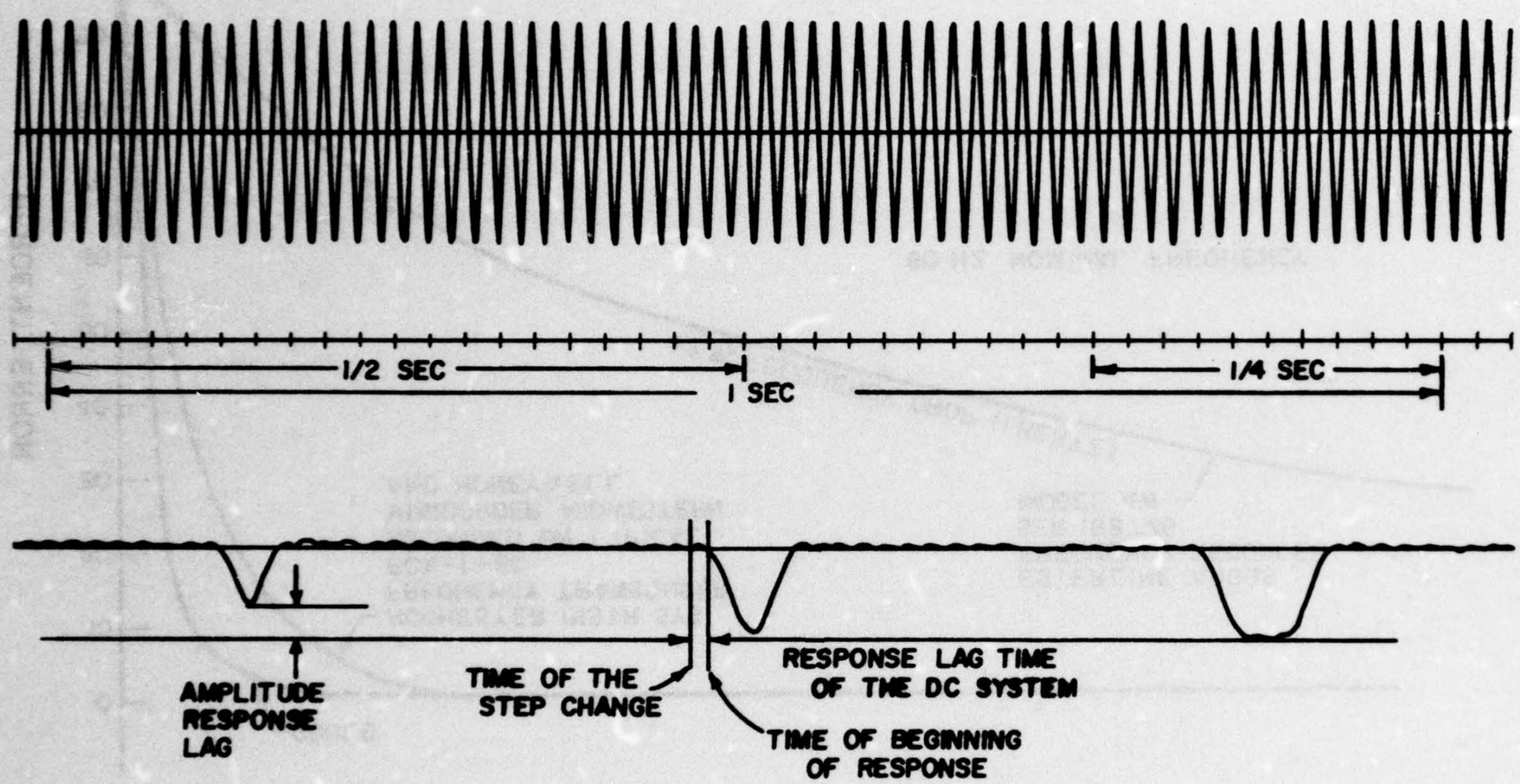

Figure 2. Two recordings--ac and rms--of same signal.

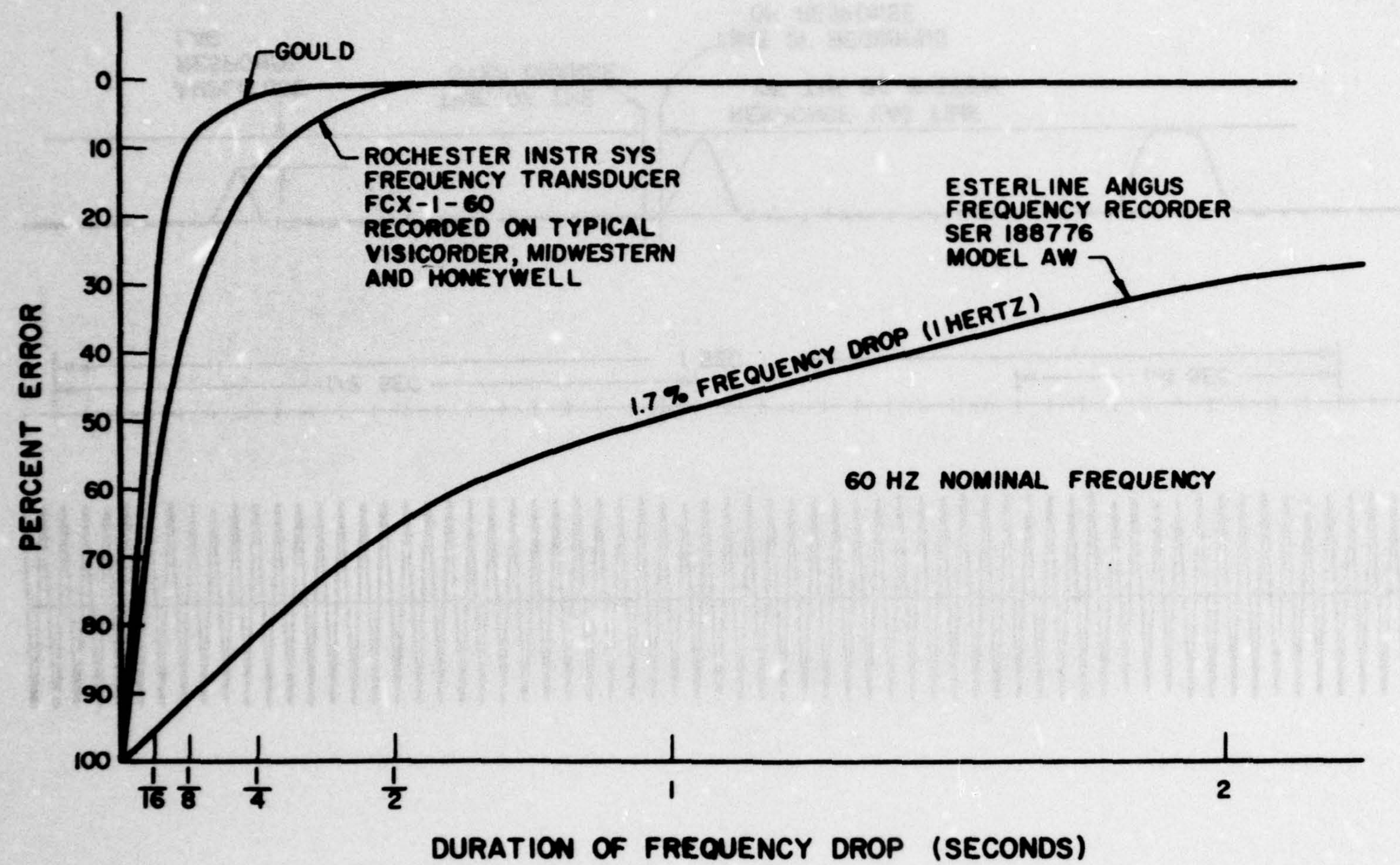

Figure 3. Error analysis and comparison of instrument response for frequency change.

used in these tests are typical of many other frequency transducers available. Results of the tests for a 1-Hz frequency decrease showed this transducer to be accurate only for frequency deviations of 1/2 second or longer, as shown in the data recordings in Appendix B.

Dranetz Series 606 Power Line Disturbance Analyzer

The measurement technique used by the Dranetz system for frequency measurements is based on counting cycles over a 1-second interval. Primary checks indicated that although it functioned properly within its designed range, it would not respond to the required test signal and was not compatible with the range of testing. No printout of data was available for incorporation into this report.

Gould 2200 Recorder

The Gould recorder with its frequency deviation plug-in unit provided superior response to frequency deviation compared to other recorders tested; it had slightly improved performance over that of the Midwestern Oscillograph and Honeywell Fiber Optic recorder. (See data recorded in Appendix B.)

Discussion of Results

Of the equipment tested, the Gould 2200 Recorder provided the best performance. This instrument demonstrated a performance equal to or better than the more expensive Honeywell and Midwestern optical recording systems. The Gould recorder was also much easier to set up and operate than the optical recorders and produced a higher quality trace. The Gould recorder system provides information on the duration of the transient excursions and reasonable accuracy as to the amount measured. Transient excursions which can be accurately measured are limited by the conditioning equipment and by the chart drive mechanical and electrical characteristics. For the Gould recorder, chart speed accuracy is specified by the manufacturer as ± 1/2 percent synchronous with line frequency. The chart wander is specified as .25 mm maximum. Other characteristics detrimental to accuracy that are not usually defined, but are important because they add to total error are flutter caused by line frequency distortion; slope and backlash in the gear train; trace width; and paper slip. Normally, preprinted grid-line types of recorders such as the Gould yield accuracies limited by the above characteristics coupled with reasonable human error of about 2 percent of full scale at best. This 2 percent is not significant within the range for which this instrument is recommended. Augmenting the Gould recorder system with the Dranetz line monitor, which provides a printed record of the maximum voltage and frequency excursions, and the time of their

occurrences, would solve this problem. The combined system would exceed specifications required for utility and medium-grade power systems, but would be insufficient for precise grade power systems measurement.

The optical recording systems exhibited a higher slew rate, and therefore would be better suited for direct waveform recording and analysis. Both recording systems were limited by the frequency and voltage transducers used; to obtain precise power levels of analysis, special-purpose transducers employing new concepts would need to be developed. However, the transducers tested will perform satisfactorily for medium- and utility-grade power systems testing.

The tests confirmed that precise grade tests can only be performed by a transient digitizer system such as the Erdac III by Macrodyne (see Appendix A), with subsequent computer analysis of the data. The technology exists to provide on-line precision grade analysis of test data, but such systems do not exist on an off-the-shelf basis. Such a system would require some hardware and software development, but could be implemented in a portable package by using microprocessor technologies.

4 CONCLUSIONS AND RECOMMENDATIONS

The Gould 2200 Recorder provided the best performance of the systems tested. However, because its accuracy is limited by paper slip and pen width, it is recommended that the Gould recorder system be augmented by the Dranetz line monitor. The Dranetz will provide the required accuracy while the Gould will present a continuous recording for observation. This combined system would exceed specifications required for utility- and medium-grade power systems.

The more expensive Honeywell and Midwestern optical recording systems are limited by the frequency and voltage transducers used with them. However, the transducers tested will perform satisfactorily for medium- and utility-grade power system testing.

Precise-grade tests can only be performed by a transient digitizer system with subsequent computer analysis of the data. Although feasible, such a system is not currently available on an off-the-shelf basis, and would require some hardware and software development.

APPENDIX A:
MANUFACTURERS' INFORMATION

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Esterline Angus Rapid Response AC voltmeters

Record millisecond voltage transients with one-tenth second expanded scale AC voltmeter

Esterline Angus
Box 24000, Indianapolis, Indiana 46224
Telephone (317) 244-7611

Rapid response voltmeters

Voltage transients that are too short-lived for the ordinary voltmeter to record can play havoc with your computers or digitally controlled machines. But minute voltage transients are easily captured by Esterline Angus rapid response voltmeters. They accurately record 100 millisecond voltage transients. Even two-volt changes as short-lived as 30 milliseconds will cause a noticeable pen deflection.

Esterline Angus has two types of voltmeters with 1/10 second rapid response: the single 4½" channel curvilinear (Series "A") model, and the analog-event (Series "A") with a 2¾" active width curvilinear analog channel and up to eight event channels.

Both models can troubleshoot computers plagued with spikes. They can record line, bus, and feeder voltage on plant power systems, check out power user complaints, or accurately study voltage regulator operation.

One-third second expanded scale voltmeters, too

If one-tenth second rapid response isn't needed, an expanded scale voltmeter with one-third second normal response is available at lower cost in Single-channel and two-channel rectilinear (Series "S") models in two-channel rectilinear and four-channel rectilinear (Series "E") models and in single-channel rectilinear and curvilinear and analog event curvilinear (Series "A") models. The one-third second response instruments are invaluable in making motor-overload studies, monitoring welding, and investigation of power rectifier input and output voltages.

Variety of styles

Voltmeters are available in many ranges, case styles, chart drives. You can choose from more than 50 combinations of chart drives in Series "A" recorders from five basic chart drive mechanisms, including hand-wound spring, motor-wound spring, synchronous, phantom, and selsyn. The seven Series "S" chart drives are operated by synchronous motors with 14 instantly adjustable chart speeds available. Series "E" cases offer two or four-channel models with 11" wide charts and 12 chart drive types. Series "A", "S", and "E" recorders feature dependable ink writing systems. Event pens can be added to record in both the left and right chart margins. Two additional event pens can be added to records in the center of the chart on Series "E" recorders.

Principle of operation

Both one-tenth and one-third second response instruments use a permanent magnet moving coil measuring element. The upper one-fourth of the range being measured covers the upper 80 percent of the chart width. The remainder of the voltage range is condensed in the lower 20 percent of the chart width.

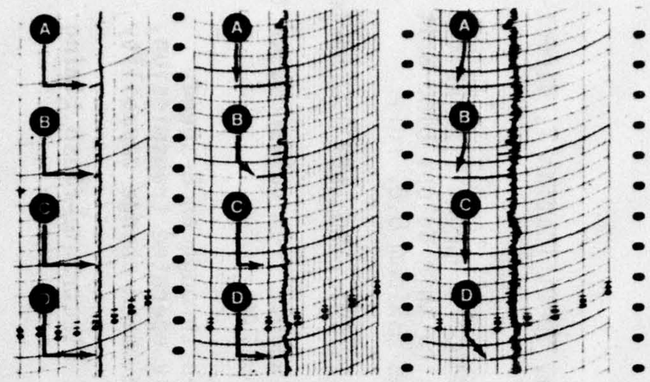
These recorders operate at frequencies from 50 to 60 Hz. They can be calibrated for higher frequencies such as 400 Hz. The Rapid Response recorder draws approximately 225 milliamperes at full scale voltage. The one-third second response recorder draws 150 milliamperes at full scale voltage. A mechanical and electrical zero permit an immediate instrument check.

The recorders use a rectifier and filter circuit, and are calibrated in terms of RMS values for sine wave input. Compensation is added to minimize the effects of common sine wave distortions. This gives these instruments the ability to record RMS values more accurately than the average instrument.

Accuracy of the instruments is plus or minus one percent of the mid-scale voltage on AC (sine wave).

Three Esterline Angus Voltmeters made these records simultaneously when a 10-volt drop was applied to the circuit. Conventional voltmeter at left without expanded scale; one-third second response expanded scale instrument in center; one-tenth second response instrument at right. Letters on charts indicate duration of each 10-volt drop:

A 250 milliseconds (15 Cycles on a 60 Hz circuit)
B 100 milliseconds (6 Cycles on a 60 Hz circuit)
C 66.6 milliseconds (4 Cycles on a 60 Hz circuit)
D 33.3 milliseconds (2 Cycles on a 60 Hz circuit)



Specifications

Ranges*:	Rapid Response (one-tenth second)	Ranges*:	Normal Response (one-third second)
	0/ 90—130 V AC 0/100—140 V AC 0/180—260 V AC 0/200—280 V AC 0/360—520 V AC 0/400—560 V AC		0/ 90—130 V AC 0/100—140 V AC 0/24—32 V DC** 0/180—260 V AC 0/200—280 V AC 0/360—520 V AC 0/400—560 V AC
Accuracy:	1% of mid-scale voltage	**Accuracy:**	1% of mid-scale voltage
Frequency limits*:**	50-60 Hz	**Frequency limits***:**	50-60 Hz
Current at full scale:	225 MA	**Current at full scale:**	150 MA
Instruments available with one-tenth second expanded scale voltage ranges:	A 601C single 4½" channel, curvilinear A609C 2¾" analog channel, curvilinear. 8 event channels (Charts are stocked for 0-100—140 volt range. Charts for other ranges can be supplied.)	**Instruments available with one-third second expanded scale voltage ranges:**	A601C single 4½" channel, curvilinear A602C two 2" channels, curvilinear S602R two 2³⁄₁₆" channels, rectilinear A609C 2¾" analog channel, curvilinear with 8 event channels A601R single 4½" channel, rectilinear S601R single 4½" channel, rectilinear E1102R two 4½" channels, rectilinear E1104R four 2³⁄₁₆" channels, rectilinear
Response:	one-tenth sec. for full voltage reading	**Response:**	one-third sec. for full voltage reading
Ambient temperature range:	+20° to +120°F	**Ambient temperature range:**	+20° to +120°F

*One, two or three ranges may be combined in one instrument provided higher ranges are even multiples of lowest range.
**Recording DC voltage having AC ripple content in excess of 2% requires special consideration.
***Calibrations for higher frequencies (such as 400 Hz) usually can be furnished at no extra charge.

Midwestern Oscillograph Specifications

RECORDING MEDIA:	8 inch wide, Specification 1, direct-print paper	
PAPER CAPACITY:	250 feet standard duPont Lino-Writ 5 or 475 feet extra thin duPont Lino-Writ 5, 4 1/2 inches maximum O.D. roll	
GALVANOMETERS:	Standard M.I. 102, 120, and 126 series	
RECORDING OPTICAL ARM:	12 inch (distance from galvanometer to recording medium)	
TRANSPORT DRIVE SYSTEM:	Motor driven through an 8-speed, electrically operated transmission, with remote speed change capability	
TIMING LINES:	Full-width, electronic-flash timing lines	
COOLING:	Forced ventilation of power supply and galvanometer lamp; cooling air is filtered through fiberglass as it enters the oscillograph	
DIMENSIONS:	BENCH UNIT	RACK UNIT
HEIGHT:	9 inches including mtg. feet	8-1/4 inches
WIDTH:	13-5/8 inches	19 inches
LENGTH:	19-1/2 inches including knobs and fuses	20 inches
WEIGHT:	65 pounds	75 pounds

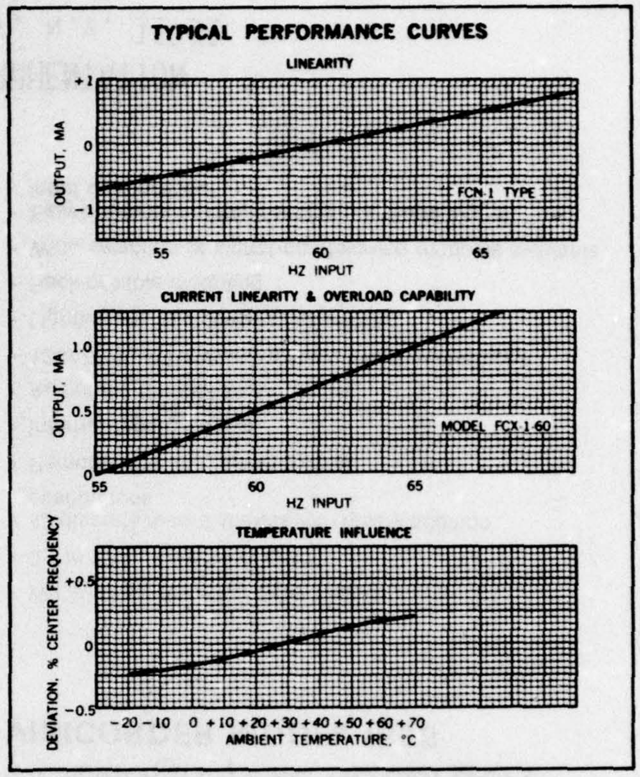
ROCHESTER
INSTRUMENT
SYSTEMS
Sales Offices in Principal Cities of The World

SERIES FCX-1, FCN-1, & FFN-1 FREQUENCY TRANSDUCERS

- Outstanding Overload and Temperature Performance
- Non-Potted Mechanical Assembly
- Compact Size
- 0.02% Voltage Rejection
- 0.02% Load Resistance Effect
- 0.5% Accuracy Class
- 0.02% Linearity

The RiS FCX-1 and FCN-1 Series of Frequency Transducers are precision engineered instruments designed to provide a constant-current output into a variable impedance load. The latest techniques are used in their design and manufacture to assure maximum performance under the most demanding conditions.

The highest-quality silicon components, including high-performance integrated circuit amplifiers, are used exclusively in these instruments. The components are packaged on high-quality, military-grade, G-10, epoxy fiberglass circuit boards. The electronic circuits and supporting components of these transducers are mounted on an integral steel cradle, which is housed in a welded steel enclosure. There is no potting; removal of two screws provides access to the entire assembly.



OPERATION

Frequency to dc translation is accomplished through the use of a diode-pumped integrator circuit. High-quality components such as field effect switching transistors and metalized polycarbonate capacitors are used to assure excellent performance.

A precision dc reference supply provides a zero drift bias level to the input switching stage. Zero crossing of the input waveform causes the input switching stage to change state, and transfer a charge through a precision reactive element to an integrating stage. The dc level in the integrating stage is then amplified to a constant current output signal in the high-gain operational amplifier output stage. Surge protectors and electrostatic shields are employed to provide input and output surge protection. Stability, high resolution and broad field adjustability are provided through the use of 20-turn precision potentiometers for zero and span.

DRANETZ Worldwide Leadership in High Speed Precision AC Instrumentation

SERIES 606 POWER LINE DISTURBANCE ANALYZER

DISTURBANCES MEASURED

- Transient Impulse (0.5 - 100μsec.)
- Sag/Surge (instantaneous cycle-to-cycle RMS variations)
- Slow-Averaged Steady-State RMS Variations
- Under/Over Frequency (optional)
- Power Interruptions

FEATURES

- Precise Time Correlation
- Audible Alarm
- Battery Carry-Over
- Prints only upon disturbance
- Automatic Daily Summary
- Alphanumeric Printout
- No interpretation required
- Portable (16 lbs.)

The 606 is designed specifically for monitoring power lines (single or three phase) connected to line-sensitive electronic equipment. Using a microcomputer and an alphanumeric printer, the 606 classifies each disturbance into IMPULSE, SAG/SURGE, or SLOW AVG change. When preset thresholds are exceeded, the instrument prints out time, classification, channel, magnitude, and duration. Data is also accumulated for end-of-day printout. Since the instrument prints only when a threshold is exceeded, no paper is wasted. The printed record is an easy-to-read list of disturbance events that can total more than 36,000 within each 24 hour time period.

FOR FULL INFORMATION AND DETAILED SPECIFICATIONS WRITE FOR BULLETIN 606.

Gould Inc., Instrument Systems Division
3631 Perkins Avenue Cleveland, Ohio 44114

SPECIFICATIONS

General

Number of Analog Channels	One to Six (Depending upon Model Number).
Number of Event Marker Channels	Left & Right Margin. Additional are Optional.
Channel Span	50 or 100 mm (Depending upon Model Number).
Trace Presentation	Rectilinear
Trace Width	0.01 inch nominal at 5mm/sec chart speed.
Marking Method	Pressured ink.
Marking Fluid Capacity	One or two one-ounce replaceable throw away cartridges (sufficient for one year under normal operation).
Chart Speeds	5,10,25,50,100, and 200 mm/sec plus divide by 60 or 100.
Chart Speed Accuracy	±0.5% synchronous with line frequency.
Chart Length	275 feet (83 meters)
Chart Width	130mm, 250mm and 380mm
Divisions per Channel	50 Divisions on 50 mm Channels 100 Divisions on 100 mm Channels
Time Lines	Every mm, accentuated at 5 and 100mm.
Chart Travel Direction	Top to Bottom
Paper Discharge	Front
Chart Wander	0.25 mm maximum
Operating Temperature Range	0° to +50°C (+32° to +122°F)
Storage Temperature Range	-40° to +70°C (-40° to +158°F)
Humidity	95% at 32°C (+90°F) Non-Condensing
Vibration and Shock	Standard Commercial Practice.
Principle Dimensions	Refer to Outline Dimensions (Following Model Numbering System Tables).

SPECIFICATIONS (Cont'd)

Electrical

Input Circuit	Single ended, floating (Phone jack or preamp connector)
Input Impedance	100K ohms ±1% (Recorder without Preamplifiers)
Input Signal	±2.5V for full scale deflection of 50, or 100 mm channels.
Frequency Response	At 100 millimeter amplitude: d-c to 30Hz ±1mm At 50 millimeter amplitude: d-c to 50Hz ±1mm At 40 millimeter amplitude: d-c to 55Hz ±1mm At 10 millimeter amplitude: d-c to 100Hz ±1mm, 3 dB down at 125Hz
Rise Time (10% to 90% full scale with less than 1% overshoot)	At 100 millimeter amplitude: less than 8 milliseconds At 50 millimeter amplitude: less that 5 milliseconds At 40 millimeter amplitude: less than 4 milliseconds
Non-Linearity	±0.35% of full scale
Pen Position Control	Infinitely adjustable ±5 volts d-c. One per channel.
Maximum Allowable Signal Input Voltage to Avoid Damage	±50 volts dc or peak ac (recorder without preamplifiers).
Maximum Safe Common Mode Voltage	500 volts dc or peak ac.
Common Mode Rejection Ratio	60 dB at 60Hz (R_s = 1 kilohm, without preamplifiers). 80 dB at dc (R_s = 1 kilohm, without preamplifiers)
Signal Limiters	Built-in adjustable electronic and mechanical
Zero-Line Instability (Drift) After 15 Minute Warm-Up	±0.1% of full scale for 24 hours ±0.025% of full scale per ° C ±0.10% of full scale for ±10% line voltage change
Gain Instability	±0.1% of reading for 24 hours ±0.05% of reading per ° C ±0.05% of reading for ±10% line voltage change
Remote Chart Drive Start/Stop (Standard on all Recorders)	Actuated by an external switch closure at any preselected chart speed.
Internal Timer (Standard on all Recorders)	Produces 10 millisecond duration pulses at programmable repetition rates depending upon line frequency as follows:

Line Frequency	Programmable Repetition Rates
50 or 60 Hz	0.1, 1, 10 and 100 second; 0.01, 0.1 and 1 minute
400 Hz	0.1, 1 and 10 second; 0.001, 0.01 and 0.1 minute

Power Consumption	50 to 60Hz: 160VA +50VA per channel (100W+41W per channel) 400Hz: 300VA +50VA per channel (200W+41 W per channel).

The ERDAC III

Macrodyne Industries, Inc.
1845 S. Bundy Drive
Los Angeles, CA 80025

COLLECT several waveforms simultaneously
EXAMINE analog signals in real time
FREEZE and examine the important events
MEASURE time and amplitude values quickly
REMEMBER the captured signals for detailed analysis
STORE traces on computer quality tape cartridges
PLAYBACK exactly the record segment selected for review
ANALYZE the data with precisely the time resolution desired

CURSOR GIVES STARTING ADDRESS OF DATA AFTER TRIGGER POINT

An adjustable CURSOR is used to make exact settings of the desired trigger point in time. Cursor location in relation to the input signal appears as a bright spot on the CRT. (Shown in top right trace.) Numerical LED displays indicate the exact CURSOR X address on the time axis.

The cursor can be set at any point on the X axis to capture & display a specific amount of data occurring before the trigger point. Both pretrigger location in time and the triggering voltage level are displayed on the CRT & in cursor X & Y numeric readouts. By showing exactly where the trigger occurred, an ERDAC eliminates the ambiguity in transient capture.

Input data from all the channels actually being used is frozen and displayed at once. The display can also be frozen with an external trigger source or with the manual TRIGGER button.

BUILT IN DATA STORAGE IS ON DIGITAL TAPE CARTRIDGE

Just press the tape WRITE button. Data frozen on the screen is assigned a record number and recorded on tape. (Tape, address header label shown as 025). This sequential record number is automatically incremented by 1 when each new record is written onto tape. A particular trace can be quickly searched for by its address number & displayed.

ANNUNCIATOR GIVES TAPE ADDRESS, SIGNAL AMPLITUDE, TIME AXIS ADDRESS, & CHANNEL I.D.

Like a pen, the cursor can be directed to the point on the trace to be measured by using the CURSOR PUSHBUTTONS. It is coupled with the LED displays to provide accurate measurements of waveform propagation times, transient voltage levels, etc. Amplitudes of several signals can be quantitatively compared at the same point in time. All channels are displayed without time skew & the cursor can be stepped from Trace 1 to Trace 2, 3, or 4, within the same time slice. Amplitude values for each point where the cursor is stopped, are automatically shown on the CURSOR Y display.

To erase the CRT, toggle the Single Shot switch. The memory starts collecting input data again, until frozen by a triggering event. The ERDAC will also reset automatically & gather 70 separate experimental records on each cartridge while unattended.

STORED RECORDS ARE TAGGED FOR SEARCH & DISPLAY

Because each 4096 word record is labeled with an address header as it is stored on tape, it is possible to quickly search for particular traces and display and output them without reviewing the entire tape. No more miles of chart paper to catalog and store either! You can efficiently edit the tape and make accurate hard copy of only the selected blocks of data required.

The best of two worlds: real-time memory and permanent storage. The long-term storage medium is 3M's DC300A magnetic tape cartridge designed specifically for digital recording and consistently high reliability. Each cartridge will hold seventy 2048 word records, or thirty-five 4096 word records. This is equivalent to over 20 hours of data when using the .5s sampling rate. Cartridges are easily loaded through the sliding door on top of the ERDAC.

The proven recording quality of the 3M digital tape cartridge makes it easy to reproduce signals accurately. Using the ERDAC, a particular record address can be quickly recalled, read from tape, and locked in memory. Recorded signals appear on the screen for examination. The MEMORY WRITE/INHIBIT switches enable data from several cartridges to be locked in memory and displayed for comparison with incoming signals. Each cartridge can be used over and over again to store new data.

You may add ancillary information to every waveform recording too! Simply label each record on tape with as many 10-bit words as you like. Time, barometric pressure, temperature, and other digitized information presented to the I/O bus will be recorded whenever a 4096 or 2048 word record is written onto tape.

Both serial and parallel input/output for data exchange are built in. The information can be taken directly from the ERDAC to a computer for Fourier analysis, correlation, smoothing, etc.; or data can be transmitted over telephone lines in serial form with the appropriate modem.

APPENDIX B: DATA RECORDINGS

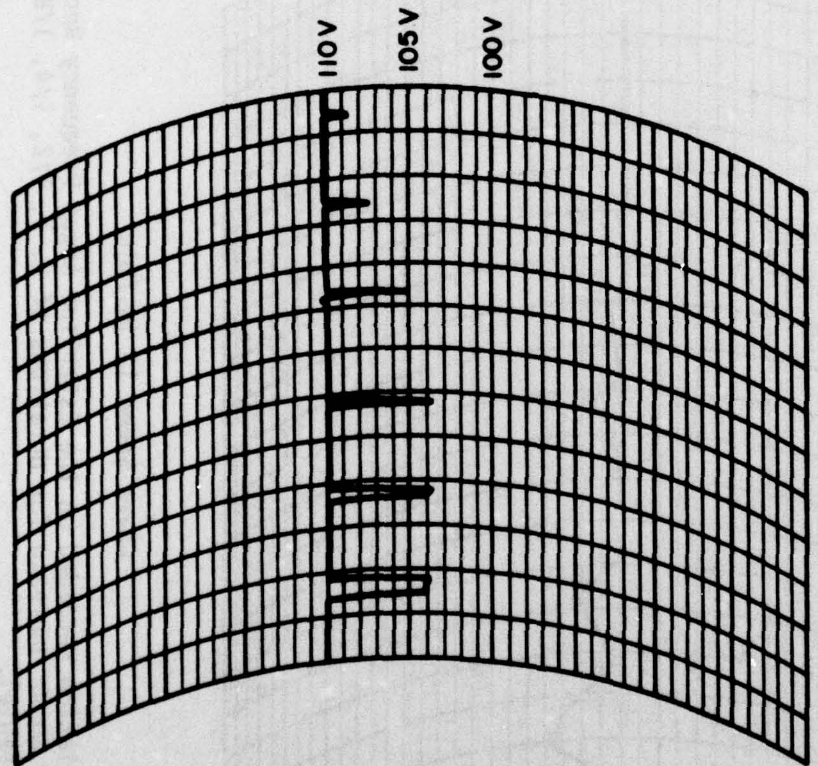


Chart Speed 12 in./min

Typical test voltage deviation recorded on the Esterline Angus Voltmeter Model 6010 Series 197285. Nominal voltage 120 V rms. Five percent voltage drop for durations of 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 seconds (100 percent repeatable).

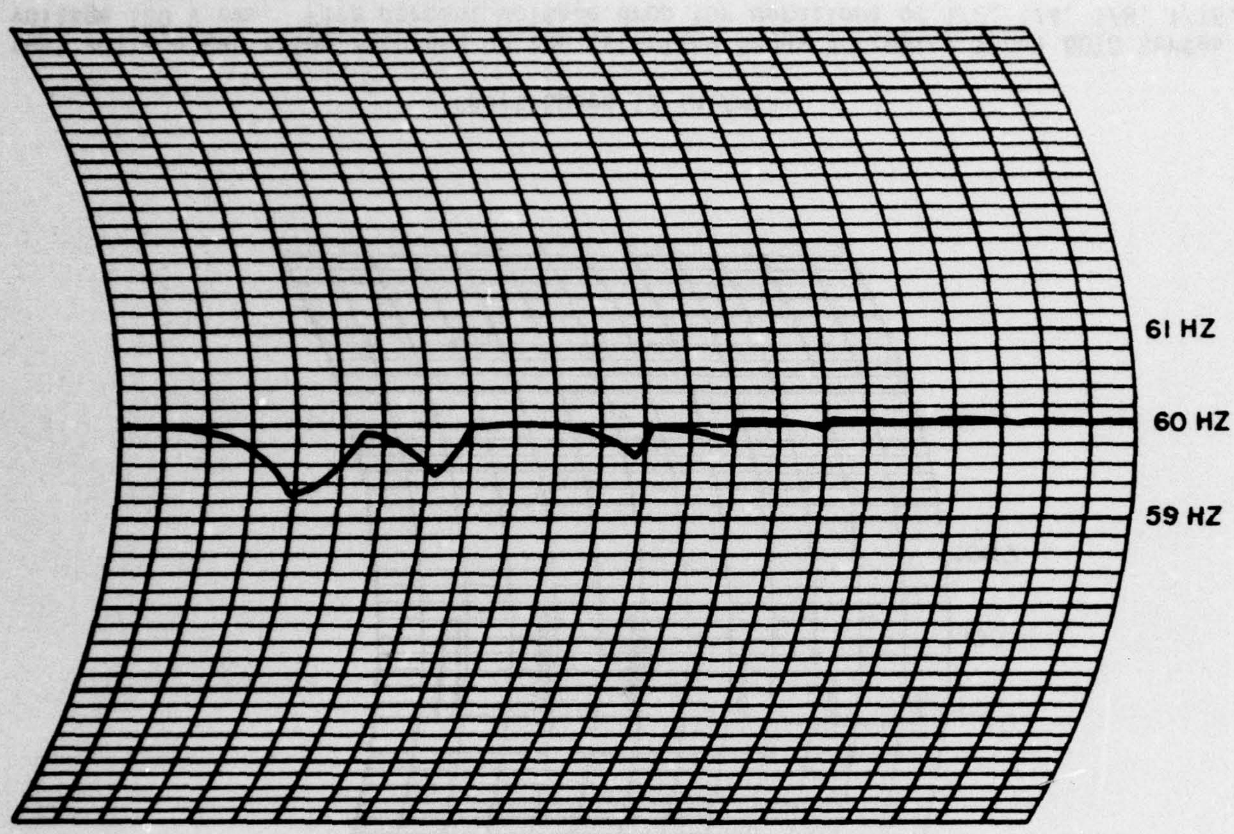


Chart Speed 12 in./min

Typical test frequency deviation recorded on the Esterline Angus Frequency Recorder Model AW Series 188776. Nominal frequency 60 Hz decrease for durations of 2, 1, 1/2, 1/4, 1/8, 1/16, 1/32, and 1/64 seconds (100 percent repeatable).

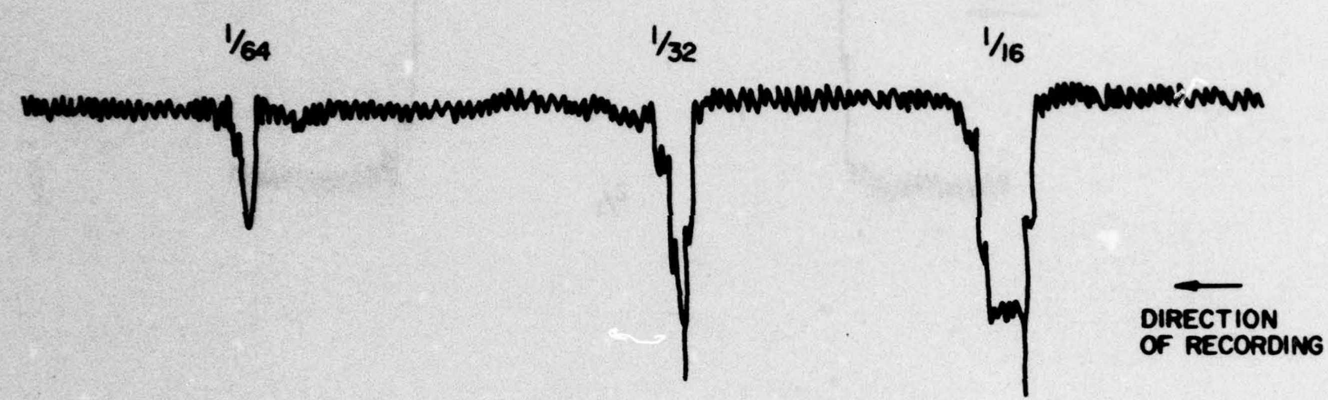


Chart Speed 5 in./sec

Typical test voltage deviation recorded on the Midwestern Oscillograph Recorder (100 percent repeatable).

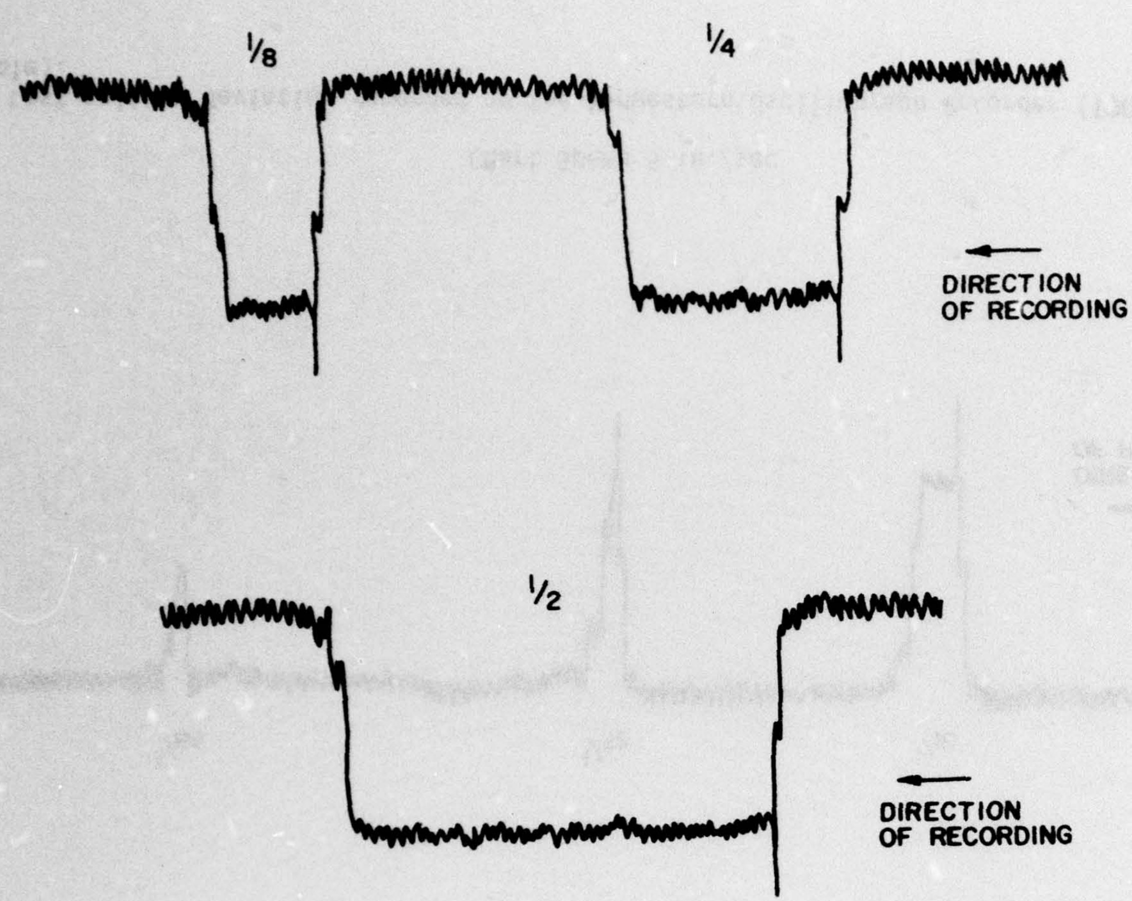
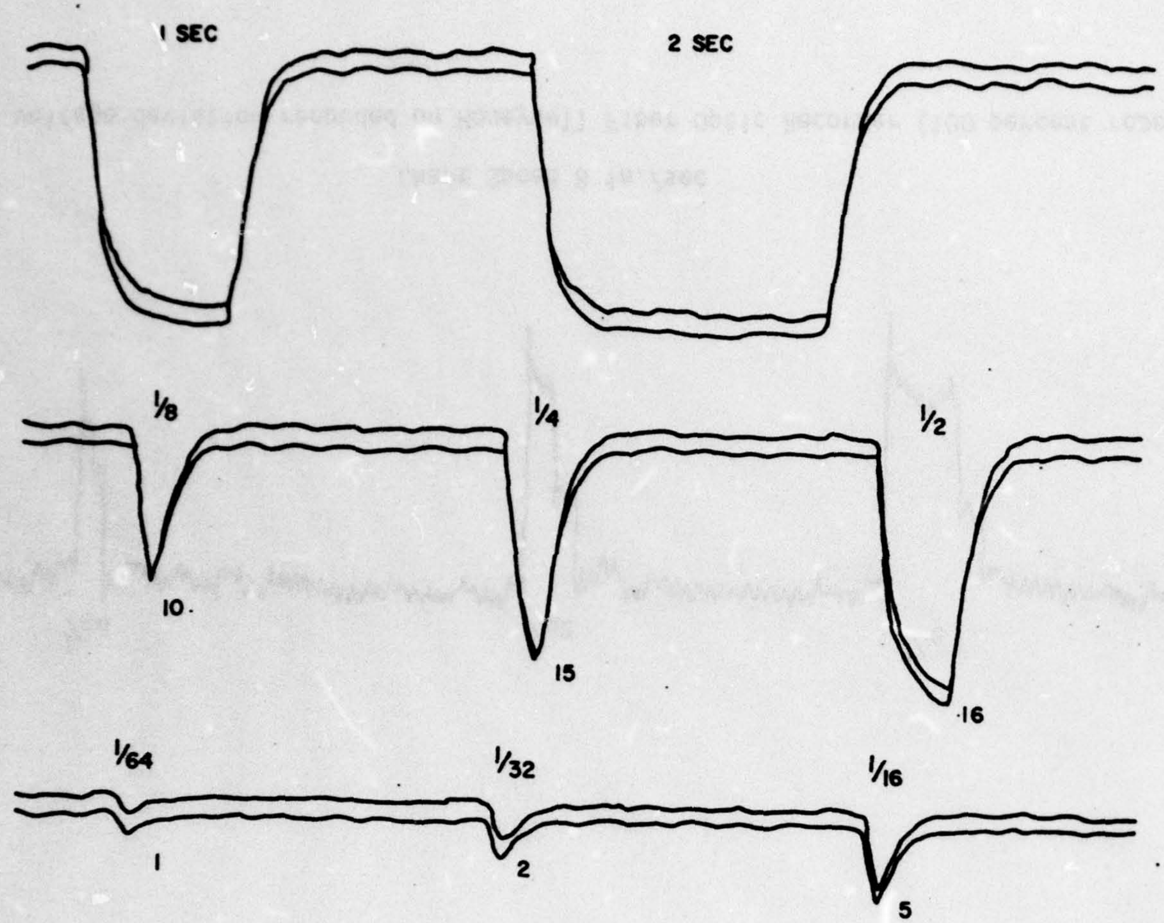


Chart Speed 4 in./sec

Typical test voltage deviation recorded on the Midwestern Oscillograph Recorder (100 percent repeatable).



Transducer Chart Speed 5 in./sec Recorder Chart Speed 1 in./sec

Typical test frequency deviation recorded on Midwestern Oscillograph Recorder (100 percent repeatable).

Chart Speed 8 in./sec

Typical test voltage deviation recorded on Honeywell Fiber Optic Recorder (100 percent repeatable).

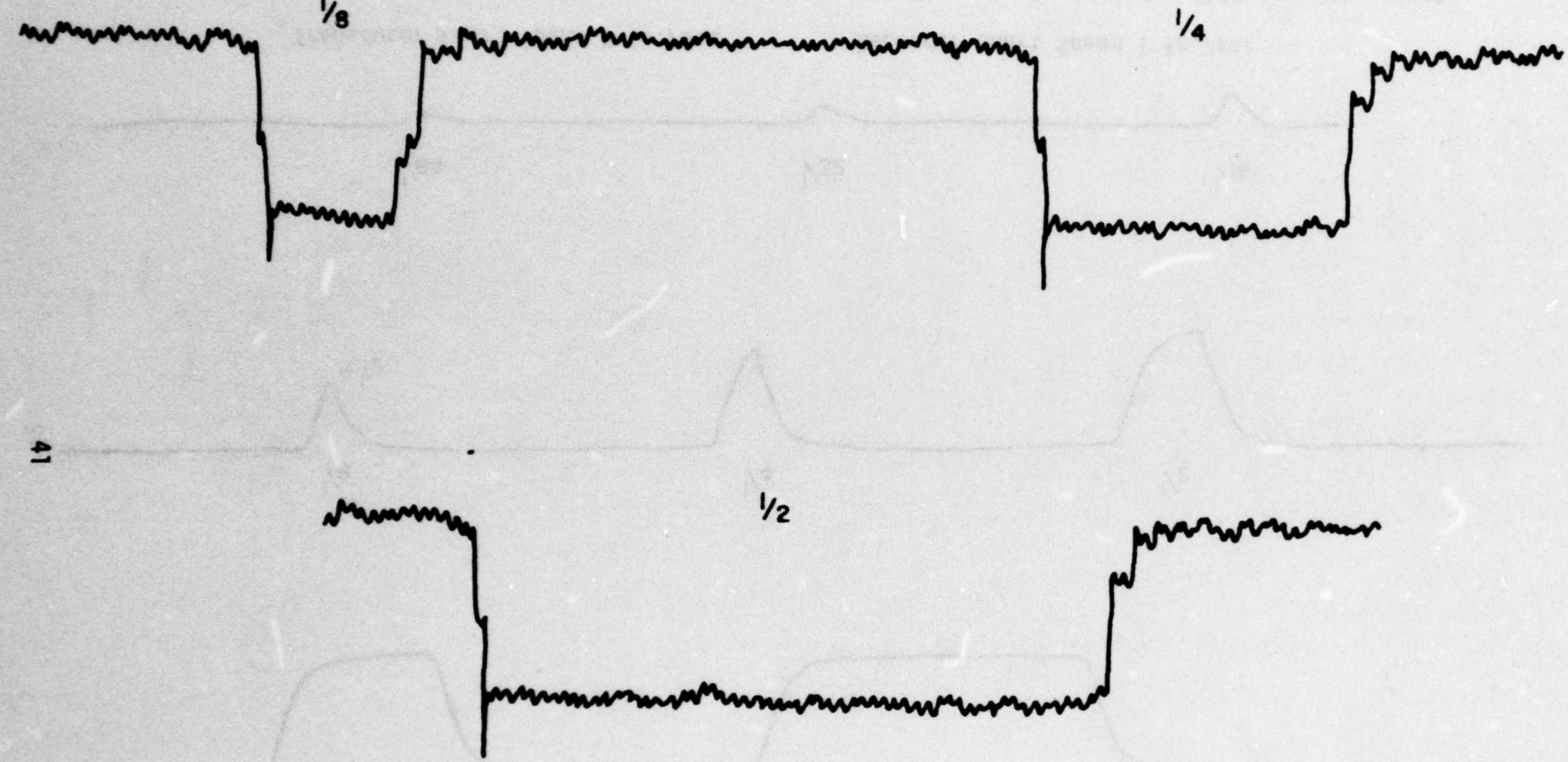
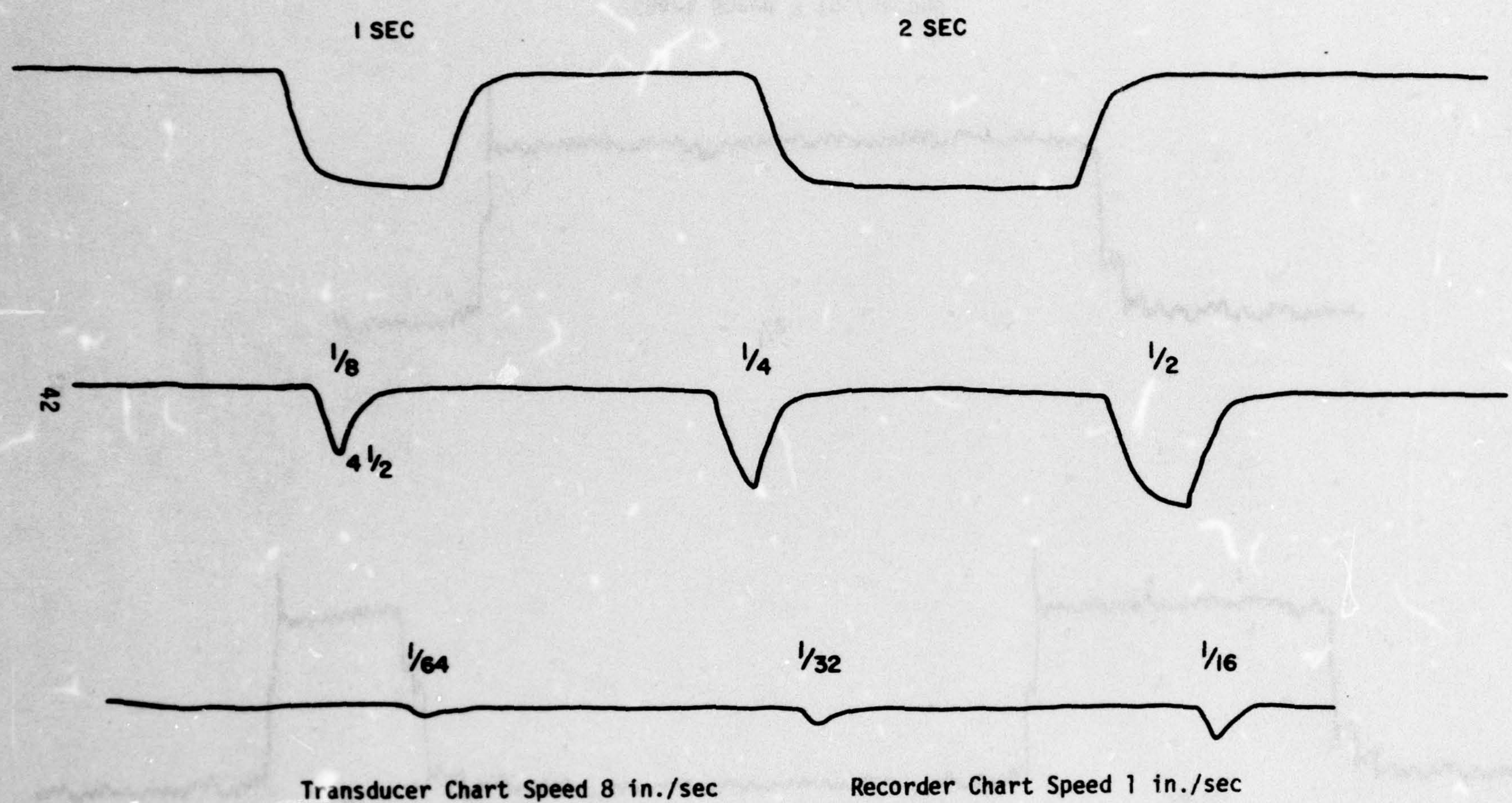


Chart Speed 8 in./second

Typical test voltage deviation recorded on Honeywell Fiber Optic Recorder (100 percent repeatable).



Typical test frequency deviation recorded on the Honeywell Fiber Optic Recorder (100 percent repeatable).

0030 CYCLES
A 107V SAG
0016 CYCLES
A 107V SAG
0008 CYCLES
A 107V SAG

0030 CYCLES
A 106EV SAG
0016 CYCLES
A 107V SAG
0008 CYCLES
A 107V SAG

0031 CYCLES
A 107V SAG
0016 CYCLES
A 107V SAG
0008 CYCLES
A 106V SAG

A 107V SAG
0030 CYCLES
A 107V SAG
0016 CYCLES
A 107V SAG
0008 CYCLES
A 107V SAG

0003 CYCLES
A 106V SAG
0002 CYCLES
A 109V SAG
0001 CYCLES
A 109V SAG

A 106V SAG
0003 CYCLES
A 106V SAG
0002 CYCLES
A 109V SAG
0001 CYCLES
A 109V SAG

0003 CYCLES
A 106V SAG
0002 CYCLES
A 110V SAG
0001 CYCLES
A 110V SAG
A 106V SAG
0003 CYCLES
A 106V SAG
0002 CYCLES
A 110V SAG
0001 CYCLES

Typical test voltage deviation recorded on Dranetz Model 606 (The system provides accuracy ± 1 digit.)

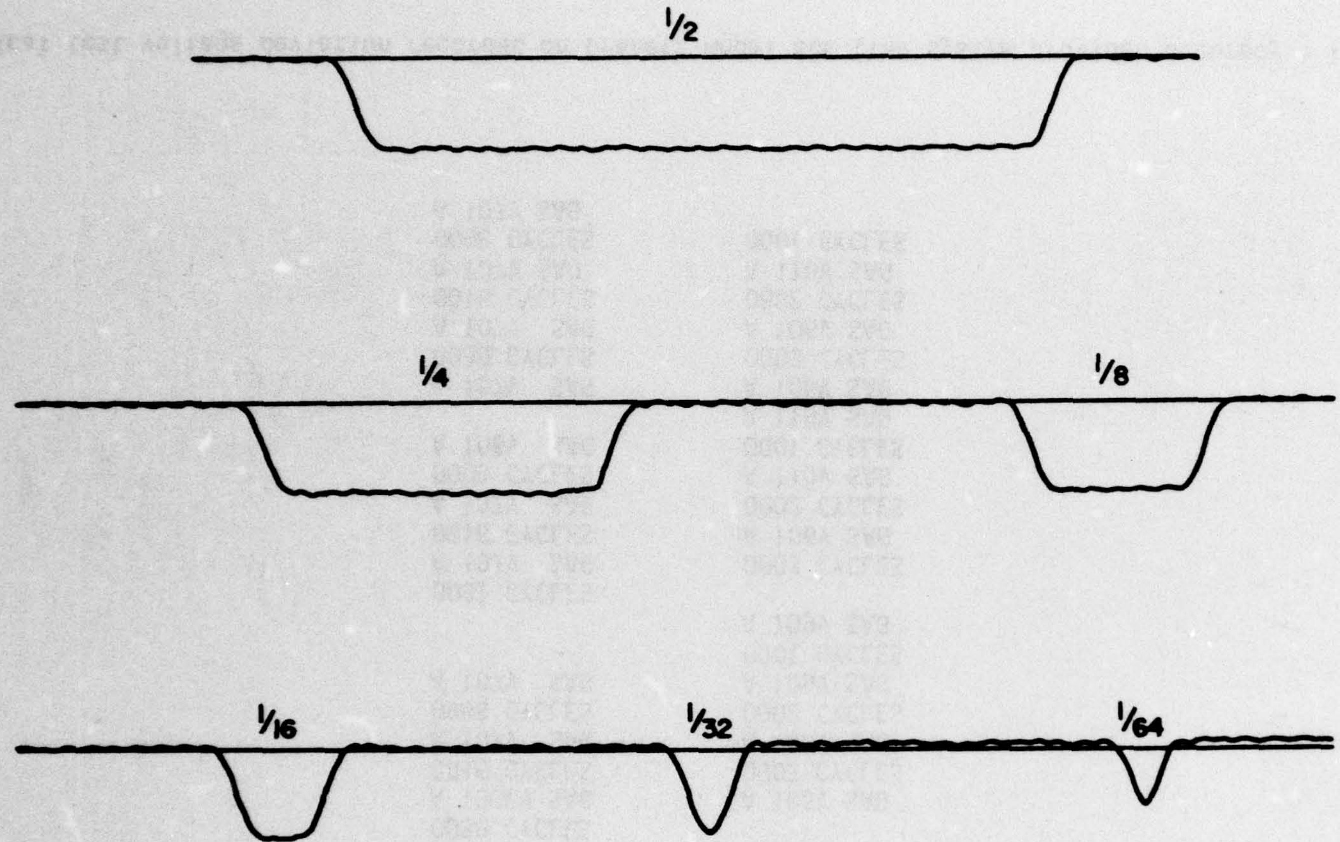


Chart Speed 200 mm/sec

Typical test voltage deviation recorded on Gould Recorder (100 percent repeatable).

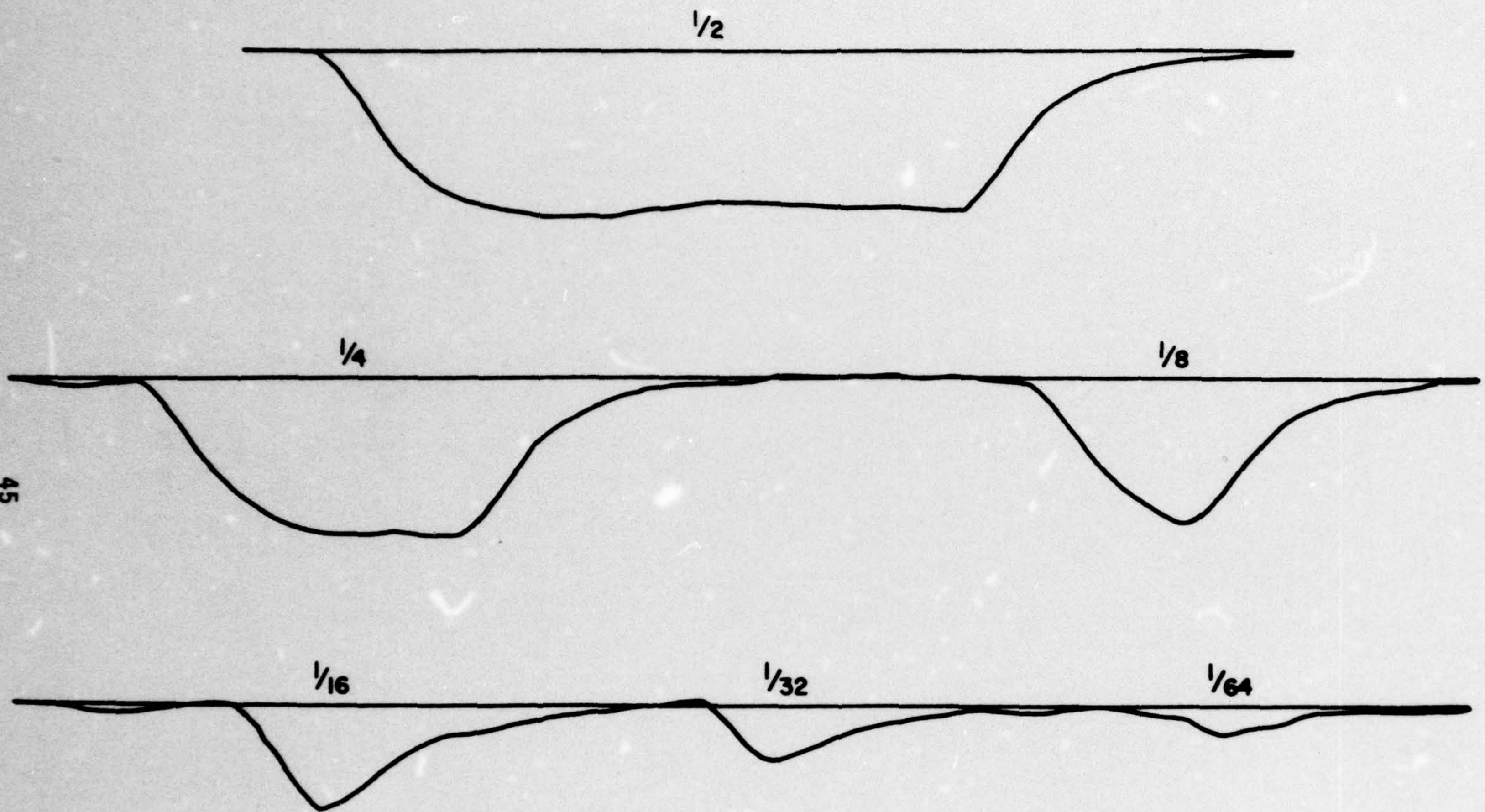


Chart Speed 200 mm/sec

Typical test frequency deviation recorded on Gould Recorder (100 percent repeatable).

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Ford, William D
Evaluation of instrumentation for testing large generator sets / by W. D. Ford, M. J. Pollock. -- Champaign, Ill. : Construction Engineering Research Laboratory ; Springfield, Va. : available from National Technical Information Service, 1978.
45 p. : ill. ; 27 cm. (Special report - Construction Engineering Research Laboratory ; E-121)

1. Diesel electric power plants -- testing. I. Pollock, Morris J. II. Title. III. Series: U.S. Construction Engineering Research Laboratory. Special report ; E-121.